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The Optimum Plant Density for Vigorous Seed Production in Safflower

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A R T I C L E I N F O

Research Article

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A B S T R A C T

Seed viability and vigor have been influenced by several factors including soil and climatic conditions, plant nutrition, fertilization, irrigation, plant population and post-harvest storages. The study was conducted to determine the appropriate plant density for vigorous seed production in safflower. The effects of row spacing (14 and 28 cm) and seeding rate (40, 80, 120, 160 and 200 seeds m^{-2}) on yield, yield components and seed quality of safflower were detected in the study. The results showed that increased seeding rates resulted in enhanced seed yield and the highest seed yield was obtained from 14 cm and 200 seed m^{-2} with 3320 kg ha^{-1}. The row spacing and seeding rate did not cause a significant difference in oil and protein contents. Laboratory emergence, germination after accelerated ageing (AA) and electrical conductivity tests were suitable for determining seed quality among the seed lots, while standard germination, cool and cold tests were not appropriate. The highest laboratory emergence percentage and germination after AA were determined in 80 seed m^{-2} but field emergence percentage in 120 seed m^{-2}. It was concluded that the 14 cm row spacing and seeding rate of 120 seed m^{-2} should be advised for high yielding seed production regardless of seed vigor in safflower.

Introduction

Because of irregular and inadequate rainfall under rain-fed conditions in arid and semiarid regions, limited crop plants are economically grown (Flagella et al., 2002; Reddy et al., 2003). One of the most important crops to be cultivated under these conditions is safflower. Due to high tolerance to drought, a reasonable seed yield without irrigation, suitable for mechanization, low labour needs and production costs, it should be placed into crop rotation systems with cool season cereals (Weiss, 2000; Bayramin and Kaya, 2009; Elfadl et al., 2009). Under these ecological conditions, determination of the optimum plant population is a crucial issue for high yielding safflower production because average productivity is relatively low due to insufficient precipitation and soil fertility.

Plant population arranged by row spacing and seeding rate may be changed considerably depending on cultivar, crop rotation, soil and climatic conditions in safflower cultivation. In California, 30 to 60 cm row spacing generally give higher yields than 15 to 20 cm spacing; however, in Nebraska, 15 to 23 cm row spacing consistently produces the highest yields (Mündel et al., 1994). Weiss (2000) summarized the results on seeding rate and row spacing, indicating that very high seeding rates reduce seed yields. At Williston, North Dakota, the maximum yields were recorded with seeding rate of 16.5 kg ha^{-1}, while the seed yield did not decrease at the higher seeding rates (Riveland et al., 1977). Mündel et al. (1994) and Elfadl et al. (2009) demonstrated that higher plant density resulted in lower branch and head number; consequently, the highest seed yield was obtained from the seeding rates of 22.5 to 45.0 kg ha^{-1} on the Canadian Prairies. Also, any information about the plant density to be used for vigorous seed production in safflower is not available. As known, safflower is a highly branched plant, which is controlled by environmental conditions, plant genetic and population. It exhibits a regular flowering order that starts the head on the main stem and continues to the primary, secondary and tertiary heads (Baydar and Ulger, 1998). This flowering pattern, which can continue up to 20-40 days, results in different sized seeds in the plant, which yield a variable seed quality (Weiss, 2000; Kaya, 2014).

The objective of the study was to determine the optimum plant density for high yielding safflower cultivation and vigorous seed production under dryland conditions of Eskişehir, Turkey.

Materials and Methods

This study was conducted at the experimental field of Eskisehir Osmangazi University in Eskişehir, Turkey. The soil type in the experimental field was clay loam, and slightly alkaline (pH=7.8), rich in potassium (2150 kg ha^{-1}), intermediate in phosphorus (33 kg ha^{-1}) and low in organic matter (1.13%). The field trials were carried out under rain-fed conditions. The climate was characterized by hot and dry summers, cold and snowy winters. Total precipitation from sowing to harvest was 87.8 mm, with a 25 years average of 151 mm. Mean temperatures during the growing period were 15.7°C.

The safflower cv. Dinçer was sown on March 21, and 30 kg ha^{-1} N and 70 kg ha^{-1} P_2O_5 (DAP, Diammonium phosphate, 18-46-0) were applied before sowing according to the results of soil analysis. Pre-emergence herbicide (Linuron 450 g L^{-1}) was applied to control weeds.

The field experiment was established at split plot design with four replicates and each replicate was considered as a seed lot for seed vigor tests. Two row spaces (narrow, 14 cm and normal, 28 cm) were considered as the main plot factors and seeding rates (40, 80, 120, 160 and 200 seed m^{-2}) as the sub-plot factors. There were six rows with 4 m long per plot for both narrow and normal row spacing.

Laboratory Experiments

Seeds were harvested separately from each plot in the field experiment and were transferred to the laboratory to determine the seed vigor. Four replicates of 50 seeds from each seed lot were germinated in three rolled filter papers with 10 mL of distilled water. Each rolled paper was placed into a sealed plastic bag to prevent moisture loss. The seeds were allowed to germinate at 25±1°C in the dark for 10 days. The seeds were considered germinated when the emerging radicle was at least 2 mm long. The germination percentage (GP) was recorded every 24 h for 10 days (ISTA, 2003).

Laboratory emergence test: Four replicates of 50 seeds from each seed lot were sown at 2 cm depths in sand in a seedling tray (30×20×7 cm) to determine the laboratory emergence percentage (LEP). The seedlings were grown in an incubator at 25±1°C for 10 days. The emerged seedlings (appearance of hypocotyls at the surface) were counted at 10 days after sowing.

Field emergence percentage (FEP): It was determined by using four sets of 50 seeds from each seed lot. The seeds were sown manually in 3 m long plots at a depth of 2.5-3.5 cm at the experimental field of the Field Crop Department. The emerged seedlings with cotyledon leaves were counted 30 days after sowing.

Cool test: Four replications of 50 seeds for each seed lot were used. They were germinated in three rolled filter papers with 10 mL of distilled water as described by germination test. The rolled filter papers were placed in a sealed plastic bag, which were put into a germination cabin at 18°C for 10 days (Hampton and TeKrony, 1995). After the incubation, germination percentage was determined according to the rules of ISTA (2003).

Cold test: Four replicates of 50 seeds from each lot were placed on three layers of filter papers with 10 mL of distilled water. Each rolled paper was then wrapped and placed into a sealed plastic bag. They were kept in a cold chamber at 10°C for four days and then transferred to germinators at 25°C (Loeffler et al., 1985).

Accelerated ageing test (AA): Two hundred seeds were sampled from row spacing and seeding rates, distributed over an aluminium screen in germination plastic boxes (11×11×3.5 cm). The boxes were filled with 40 mL of distilled water and were kept in a germination chamber for 96 hours and approximately 100% relative humidity at 45°C (Kaya, 2014). After ageing incubation, seeds were then transferred to the germination test described by ISTA (2003).

Electrical conductivity test (EC): It was performed by using four replications of 50 weighted seeds for each lot. The seeds were placed in 350 mL of plastic cups containing 200 mL deionized water for 24 hours at 25°C. The electrical conductivity of the soaked water was measured using a conductivity meter (Model WTW Cond 314i, Germany) after the incubation period. The results were expressed in μS cm^{-1} g^{-1} to take account for the variability in the seed weight among the seed lots.

Results and Discussion

For all the yield components, seed yield, oil and protein content, the main effects with their significance levels of row spacing and seeding rate were displayed in Table 1. The row spacing significantly influenced the plant height, branch number, head number, plant weight and seed yield of safflower. They were significantly higher in row spacing of 14 cm than in 28 cm. Oil and protein contents did not show any response to row spacing and seeding rate. Increased seeding rate resulted in a decrease in plant height, branch number, head number and plant weight, while seed yield was promoted. Plant height declined gradually from 69.3 cm in 40 seed m^{-2} to 60.5 cm in 200 seed m^{-2}.

An increase in seeding rate caused a dramatic reduction in branch number per plant; therefore, head number per plant diminished. The highest head number was determined in 40 seed m^{-2} with 5.58 number per plant while the lowest (2.69 number plant^{-1}) was in 200 seed m^{-2}. These results agreed with those of Umrani and Bhoi (1984) and Gonzalez et al. (1994) as they confirmed that the increasing seeding rate resulted in a significant decrease in branch and head number of safflower. Head number per plant was clearly changed depending on branch number per plant because of each branch terminating in a head (Elfadl et al., 2009; Weiss, 2000).

A remarkable decrease in plant weight was observed when the seeding rate increased. It was decreased from 194.2 g plant^{-1} in 40 seed m^{-2} to 77.0 g plant^{-1} in 200 seed m^{-2}. Zadeh et al. (2012) found a decreasing biological yield from 5354 kg ha^{-1} to 3103 kg ha^{-1} when plant population was declined. On the other hand, row spacing × seeding rate interaction showed that increased seeding rate in narrow row spacing (14 cm) led to enhanced seed yield; consequently, it reached the maximum level (3320 kg ha^{-1}) in 200 seed m^{-2}. The highest seed yield in row spacing of 28 cm was obtained from 80 seed m^{-2} with 2300 kg ha^{-1} (Figure 1). Row spacing had a greater effect than the seeding rate on safflower yield. The most favorable seed yield was obtained from seeding rate of 120 seed m^{-2}.

Table 1 The effects of row spacing and seeding rates on seed yield and yield components of safflower

Factors	Plant height cm	Branch number No. plant^{-1}	Head number No. plant^{-1}	Plant weight g plant^{-1}	Seed yield kg ha^{-1}	Oil content %	Protein content %
Row spacing							
14 cm	66.3^{a}	3.23^{a}	4.32^{a}	145.5^{a}	3100^{a}	31.2	14.7
28 cm	64.0^{b}	2.28^{b}	3.37^{b}	94.5^{b}	2160^{b}	31.6	14.2
Seeding rate (seed m^{-2})							
40	69.3^{a}	4.18^{a}	5.58^{a}	194.2^{a}	2480^{c}	31.3	13.8
80	68.3^{a}	2.99^{b}	4.01^{b}	130.6^{b}	2640^{b}	31.1	14.6
120	64.5^{b}	2.60^{bc}	3.60^{bc}	104.6^{c}	2660^{b}	31.1	15.1
160	63.3^{bc}	2.34^{c}	3.34^{c}	93.7^{c}	2610^{b}	31.3	14.6
200	60.5^{c}	1.66^{d}	2.69^{d}	77.0^{d}	2750^{a}	32.4	14.2
Summary of ANOVA							
RS(A)	**	**	**	**	**	ns	ns
SR(B)	**	**	**	**	*	ns	ns
A×B	ns	ns	ns	ns	*	ns	ns

*significant at P<0.05, **P<0.01 and ns: non-significant. Different letters in the same column show significant differences at 0.05 level, RS: Row spacing (A), SR: Seeding rate (B)

Table 2 The effects of row spacing and seeding rate on germination, emergence and seed vigor of safflower

Factors	GP %	LEP %	FEP %	Cool test %	Cold test %	EC µS cm^{-1} g^{-1}	AA %
Row spacing							
14 cm	98.0	92.0^{a}	45.9	98.3	98.6	12.95	73.1^{a}
28 cm	98.5	89.7^{b}	58.7	98.0	98.9	12.24	66.5^{b}
Seeding rate (seed m^{-2})							
40	97.6	92.3^{a}	63.4^{a}	98.8	98.8	11.71	67.3
80	98.8	92.8^{a}	59.0^{ab}	98.3	98.4	12.37	72.9
120	98.1	90.3^{a}	63.8^{a}	98.1	98.8	12.75	69.4
160	98.4	89.9^{a}	51.5^{c}	97.4	99.0	12.48	70.0
200	98.3	89.0^{b}	50.5^{c}	98.3	98.9	13.68	69.3
Summary of ANOVA							
RS(A)	ns	*	ns	ns	ns	ns	**
SR(B)	ns	**	**	ns	ns	ns	ns
A×B	ns	ns	**	ns	ns	ns	**

*significant at P<0.05, **P<0.01 and ns: non-significant. Different letters in the same column show significant differences at P<0.05. GP: Germination percentage, LEP: Laboratory emergence test, FEP: Field emergence test, EC: Electrical conductivity test, AA: Accelerated ageing test, RS: Row spacing (A), SR: Seeding rate (B)

Table 3 Correlation coefficients between standard germination and different vigor tests

	GP	LEP	CT	CoT	EC	AA	FEP	OC	PC
LEP	-0.319	-	-	-	-	-	-	-	-
CT	0.089	-0.200	-	-	-	-	-	-	-
CoT	0.004	-0.129	0.072	-	-	-	-	-	-
EC	-0.181	0.093	-0.396	-0.176	-	-	-	-	-
AA	-0.337	0.653*	-0.394	-0.447	0.445	-	-	-	-
FEP	0.302	0.091	0.520	-0.069	-0.616*	-0.233	-	-	-
OC	0.264	-0.623*	-0.031	-0.173	0.334	-0.293	-0.293	-	-
PC	0.371	0.306	-0.155	-0.016	0.223	0.471	0.291	-0.366	-
SY	-0.292	0.378	0.210	-0.190	0.478	0.608*	-0.156	-0.322	0.463

GP: Germination percentage, LEP: Laboratory emergence, CT: Cool test, CoT: Cold test, EC: Electrical conductivity, AA: Accelerated ageing, FEP: Field emergence, OC: Oil content, PC: Protein content, SY: Seed yield

The results of this study are consistent with the observations of Mündel et al. (1994), who observed that the seeding rate between 22.5-45.0 kg ha^{-1} should be recommended for optimum seed yield in safflower while a seeding rate of 7.5 kg ha^{-1} was inadequate.

Among laboratory tests, a significant two-way interaction (row spacing × seeding rate) was detected (P<0.05) for the field emergence (FEP) and germination after the accelerated ageing test (AA) (Table 2). But germination percentage was not significantly affected by neither row spacing nor seeding rate. Generally, it was about 98.0% in all the treatments. However, the laboratory emergence percentage in row spacing of 14 cm was higher than that of 28 cm, increased seeding rate led to decreasing laboratory emergence from 92.3% to 89.0%.

The seeding rate did not significantly influence the field emergence percentage while the highest emergence (63.8%) was determined at 120 seed m^{-2}. The interaction between row spacing and seeding rate demonstrated that field emergence of the seeds from 28 cm was superior to the seeds from 28 cm when seeding rate was higher than 120 seed m^{-2} (Figure 2). Germination percentage in cool and cold tests, and electrical conductivity values was not changed significantly by row spacing and seeding rate. Germination percentage after AA showed that higher seed viability was recorded at 14 cm with 73.1%. The interaction demonstrated that row spacing of 14 cm gave a better germination performance after AA than that of 28 cm except for 160 seed m^{-2} as seen in Figure 3.

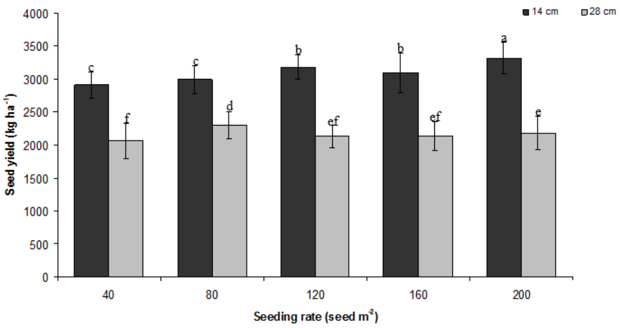

Figure 1 Changes in seed yield of safflower affected by row spacing and seeding rate

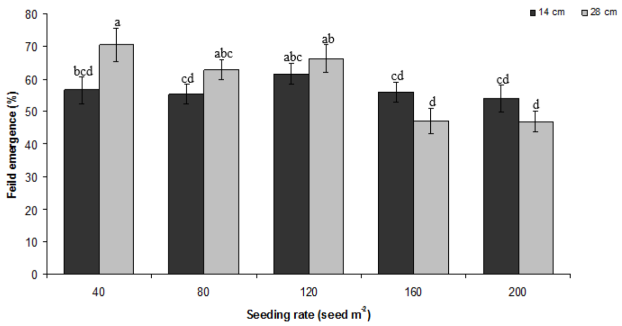

Figure 2 Changes in field emergence percentage (FEP) of safflower seeds produced by row spacing and seeding rate

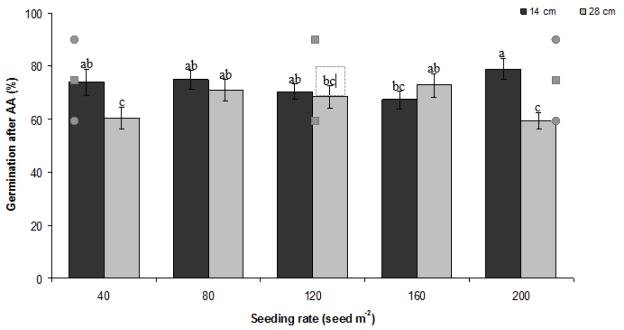

Figure 3 Changes in germination after accelerated ageing (AA) of safflower seeds produced by row spacing and seeding rate

Simple correlation coefficients calculated among the laboratory tests indicated that the laboratory emergence percentage showed a significant positive correlation with AA, but it gave a negative correlation (r= -0.623*) with oil content (Table 3). Similarly, field emergence percentage was negative and significantly correlated with electrical conductivity. The results of seed yield were positively correlated with AA and no significant correlation was observed with any of the vigor tests; indicating that seed vigor was enhanced by increasing seed yield in safflower. It may be argued that decreasing in branch and head number by increasing seeding rate led to produce the vigorous seeds from each head. Among the vigor tests, the highest correlation coefficient was observed between laboratory emergence and AA (r= -0.653*) while the best vigor test for predicting field emergence performance of safflower was the electrical conductivity test with the high correlation coefficient (r= -0.616*). A significant relationship between the electrical conductivity and field emergence suggested that the electrical conductivity is a reliable predictor of safflower seed vigor. Kaya (2014) confirmed that it was the most efficient method to rank seed vigor in safflower as indicated by Atak et al. (2002) in pea, Vieira et al. (1999) in soybean, Coimbra et al. (2009) in sweet corn.

In conclusion, we demonstrated here the first report on plant density to be used in safflower for vigorous seed production. Seeding rate is a very important to achieve optimum plant density, higher seed yield and vigorous seed production in safflower cultivation. To avoid excessive seed usage, growers tend to sow only 40 seed m^{-2} of seeds. Our findings revealed that the best row spacing for high yielding and vigorous seed production was 14 cm. Although higher seed yield was obtained if the seeding rate increased, the optimum seeding rate was determined as 120 seed m^{-2} because higher amounts did not showed a remarkable increase in seed yield. Among the seed vigor tests, electrical conductivity test gave accurate results for the prediction of field performance of safflower seed lots. It was concluded that 14 cm row spacing is suitable for both high yielding production and vigorous seeds, and seeding rate of 120 seed m^{-2} is suggested to enhance seed yield without a considerable changing in seed vigor performance of safflower.

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